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Architectural Design Approaches for Wireless Sensor Networks

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Abstract*— With ever-increasing interest in remote monitoring, and advances in embedded and sensing technologies, the Wireless Sensor Networks (WSN) research domain has experienced a great progress in recent years. The architectural design is an important concern in wireless sensor networks. This paper discusses the four different architectural approaches and protocols associated with these. It discusses the Open Systems Interconnect (OSI) layered architecture which deals with migration from the OSI paradigm to the Embedded Wireless Interconnect (EWI) architecture, a platform to develop wireless Sensor Networks with Mobile Sinks (MSSN) which proposes Transmission Scheduling Algorithm (TSA-MSSN), a system architecture capable of supporting mobile applications in wireless sensor networks, Embedded Wireless Interconnect (EWI), as an architecture platform for energy stringent wireless networks, replacing the OSI paradigm. The concept of EWI is used by a design of Low Energy Self-Organizing Protocol (LESOP) for target tracking sensor networks. Paper highlights the advantages and disadvantages of these four architectural approaches.

Keywords*— Embedded Wireless Interconnect, Sensor Networks, Transmission Control protocol, Open System Interconnect, Mobile Sinks

I. Introduction

With the advances in low-power electronics design it is made possible to develop highly integrated, low cost, micro sensor nodes, with the capabilities of sensing, processing, and wireless communications. A Wireless Sensor Network [2] is constituted by:-

a) A set of resource-constrained nodes, which are “immerse” into the spatial region to be observed and capable of performing user-defined data gathering tasks.

b) A sink node, from which information of the WSN can be accessed by the end-user.

Wireless Sensor Networks are deployed in remote hostile areas, and the sink is the only node through which the Sensor Network is first queried and then accessed for data gathering operations. Wireless sensor networks are energy-limited and application specific. These two characteristics pose new challenges in the network design. Inch-scale sensor devices are expected to operate over years with limited power supply. Thus, the energy consumption becomes the foremost design consideration, while constraints, such as throughput, latency, and fairness, become relatively less important. Sensor networks are considered for a diverse range of civil and military applications, such as environmental monitoring, home networking, medical vital signs monitoring and smart battlefield, among others.

Wireless networks architecture is divided into hierarchical layer traditionally, based on the OSI (Open System Interconnect) paradigm of computer networks [10]. In sensor networks, optimizations over the fundamental tradeoff between application specific QoS (Quality of Service) gain [9] and energy cost suggest the joint design of multiple OSI hierarchical layers, which has come to be known as the cross layer design [12].

Due to the developments in wireless sensor networks deployment in various applications new design approaches have been introduced. In this paper we are discussing four approaches which provide cross layered models, Transmission Scheduling Algorithm (TSA), Embedded Wireless Interconnect (EWI), and Low Energy Self-Organizing Protocol (LESOP).

II. TECHNIQUES USED

A wide attention has been devoted in the past years to the definition of network architecture together with the related protocols, capable of extending a classical WSN scenario with mobile sinks. This might relax the strict constraints in terms of communication and processing resources that typically affect a WSN.

The cross layer design in wireless sensor networks suggests the classical OSI reference model does not accommodate the new requirements. It also suggests that it is necessary to develop new architecture platform for replacing the existing paradigm [8]. Due to this reason, Embedded Wireless Interconnect (EWI) [17], [18] has been proposed as a universal architectural platform for wireless sensor and pervasive computing networks design. When considering the area of ITS, WSNs have been proposed as a solution for gathering real-time information about road conditions [1]. In [11], the authors present a WSN for proactively detecting and advertising possible dangerous situations on roads. In [6], a traditional WSN architecture [13] is optimized in order to achieve high cars detection accuracy, while preserving a sufficiently high network life-time.

For fixed sink sensor networks, a clustered network structure has been used. Cluster-heads can be used for routing, resource allocation among nodes in their cluster, and network management. Choosing cluster-heads optimally was shown to be NP-hard [22], with respect to the number of clusters.

From the perspective of link and physical layers, another interesting area is the power sensitive wireless communications, which have been studied under diverse conditions. In [3], [4], [5] the tradeoff between energy consumption and transmission delay was studied in radio packets scheduling, utilizing the methodology of dynamic programming. In [7], optimal power allocation was studied for maximizing the service reward in communications satellites. In [20], [23], SENMA (Sensor Networks with Mobile Agents) was studied under a sensor network topology similar to the MSSN [15]. Distributed random access algorithms were proposed. SENMA assumes a simple reach back network, where acquisition data is assumed with high redundancy. This differentiates it from MSSN, in which much higher application flexibility is provided.

II. ARCHITECTURAL DESIGN APPROACHES

There are four architectural design approaches considered in the paper which are used in wireless sensor networks. The designs can be used to gather information about the real time road conditions with help of mobile sinks. The cross layered designs have been proposed which help to improve communications in OSI model and is used in Low Energy Self-Organizing Protocol (LESOP) for target tracking in dense wireless sensor networks. Embedded Wireless Interconnect (EWI) has been proposed as universal architectural platform.

A. **DESIGN SUPPORTING MOBILE APPLICATIONS IN DISCONNECTED SENSOR NETWORKS**

This design approach focuses on a specific scenario, where mobile nodes act themselves as both end-users, when querying the WSN for specific information, and as sinks, when gathering the queried data. Due to the mobility of users and to the topology of the network, sinks experience frequent disconnections from the WSN

Method for design of disconnected sensor networks:

The reference scenario as shown in Figure 1 is constituted by an information retrieval area, over which sensor nodes are deployed, and by mobile nodes moving around it and querying for data. The hole in the middle of the area represents the presence of a building over which sensors cannot be deployed. The scenario includes the case of cars moving around at rush hours, and looking for a free parking spot in a particular region. To this purpose, a car, along its trajectory, gets temporarily connected to the network, injects a query asking for information on a specific geographical region and, later on, receives the requested data.

The reference scenario is composed by three categories of nodes:

• **Mobile sinks** comprising mobile nodes moving along the area and running services that are augmented with information originating from the WSN.

• **Vice Sinks** constituting edge nodes disseminated along the WSN perimeter and in charge of managing the communications from/to MSs; since these nodes are deployed along roads and building, they are removed from tight energy constrains and are assumed to be aware of their position and of the position of the closest VSs.

• **Sensor Nodes** comprising resource-constrained sensor nodes deployed over the monitored area and in charge of "sensing" a physical phenomenon.

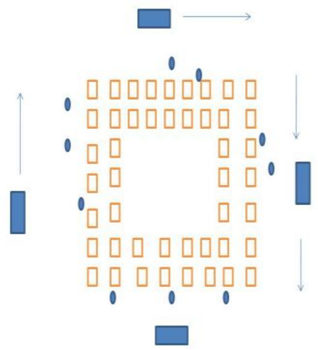

Figure 1: System model: cars move around a WSN deployed around a building and look for a free parking lot .

OMNeT++ [14] discrete event simulation system has been used to evaluate performance of the deployed sensors. MSs can in general experience periodical disconnections from the network, depending on the deployment of nodes along the road where they are moving. In order to efficiently react to unpredictable mobility pattern of the MSs, we have coupled a geographic routing strategy (able to overcome holes) with a mobility management strategy. The physical limits that affect one or more MSs gathering data from a largely deployed WSN, putting the basis of future studies in the field of WSNs for Intelligent Transportation System.

B. EMBEDDED WIRELESS INTERCONNECT FOR SENSOR NETWORKS

There are three reasons leading to Embedded Wireless Interconnect (EWI):-

1. Message exchanges in sensor and pervasive computing networks are event-centric, location-centric, and data-centric [16].

2. In ad hoc networks every node can obtain the knowledge of its network neighborhood, on which diverse ad hoc routing protocols [19] rely. This assumption may not be valid in large-scale sensor networks, where the "neighborhood" might be consisting of hundreds of sensor nodes.
3. In ad hoc networks, the potential of physical layer
Cooperation, by utilizing the broadcast nature of wireless medium, is usually neglected. This is due to the methodology of establishing virtual wired links over wireless medium in the MAC implementations.

Procedure for Embedded wireless interconnect for sensor networks

Embedded Wireless Interconnect (EWI) as shown in Figure 2 is a universal architectural platform for wireless sensor and pervasive computing networks design. EWI is composed of two layers, which are the Wireless Link layer and the System layer, respectively. Similar to the OSI reference model, EWI is also an organizing style architecture, where the System layer organizes the wireless link modules (at the Wireless Link layer) and peer wireless link modules can exchange module management information by padding a packet header to the system layer information unit [21]. Different from the OSI paradigm, EWI is especially designed for wireless interconnected low-power devices, where the node redundancy and broadcasting wireless medium can be opportunistically exploited, instead of suppressed. The node identification in EWI is based on context, i.e. data or location centric, instead of being based on symbol.

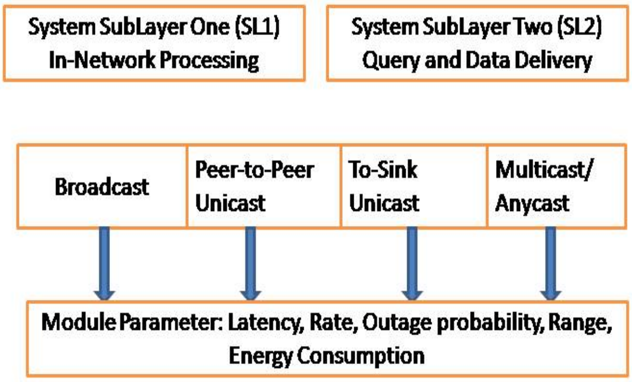

Figure 2: Embedded Wireless Interconnect Architecture

C. CROSS-LAYER ARCHITECTURE OF WIRELESS SENSOR NETWORKS FOR TARGET TRACKING

Low Energy Self-Organizing Protocol (LESOP) for target tracking as shown in figure 3 in dense wireless sensor networks has been proposed. A cross-layer design perspective is adopted in LESOP for high protocol efficiency, where direct interactions between the Application layer and the Medium Access Control (MAC) layer are exploited. Unlike the classical Open Systems Interconnect (OSI) paradigm of communication networks, the Transport and Network layers are excluded in LESOP to simplify the protocol stack. LESOP serves as the first example in demonstrating the migration from the OSI paradigm to the Embedded Wireless Interconnect (EWI) architecture platform, a two-layer efficient architecture proposed here for wireless sensor networks.

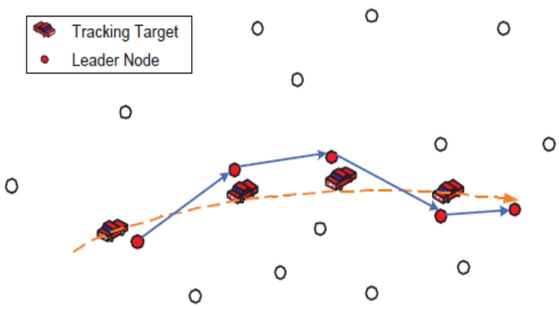

Fig. 3 LESOP for Target Tracking

METHOD

The Low Energy Self-Organizing Protocol (LESOP) is developed, which is based on the following considerations:-
i) Network QoS and Energy Consumption
ii) Low-Complexity Signal Processing Requirement
iii) Scalability
iv) Event and Location Centric
v) Separable Functionalities

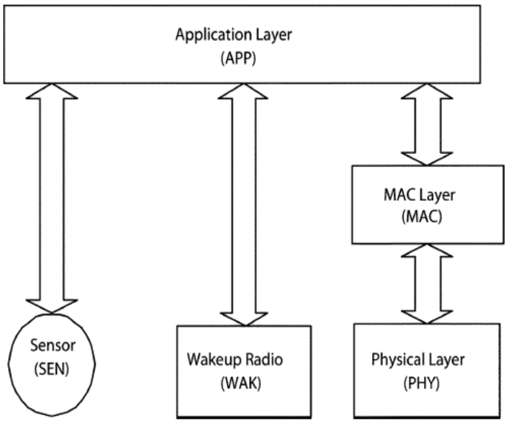

Figure 4: LESOP Architecture Cross Layers

The system module architecture of LESOP node is shown in Figure 4. The modules are named following the OSI tradition. Inter-module information exchanges are done by messages. On the other hand, inter-node communications are done by packets and busy tones. Packets go through the primary radio, while busy tones are sent by the secondary wakeup radio. For wireless communications specifically, the Transport and Network layer are omitted to simplify the protocol stack. All the radio packets have one source address, which is the location coordinates of the source sensor node. However, they do not have a destination address, and are wirelessly broadcasted to the source neighbourhood.

D. WIRELESS SENSOR NETWORKS WITH MOBILE SINKS

Wireless sensor networks with mobile sinks (mssn) has been proposed. Mssn is highly energy efficient because the multi-hop transmissions of high volume data over the network are converted into single-hop transmissions. The transmission scheduling algorithm (tsa-mssn) is proposed, where a parameter¸ is employed to control the tradeoff between the maximization of the probability of successful information retrieval and the minimization of the energy consumption cost. The implementation of the tsa-mssn has a complexity of *o*(1).

Method

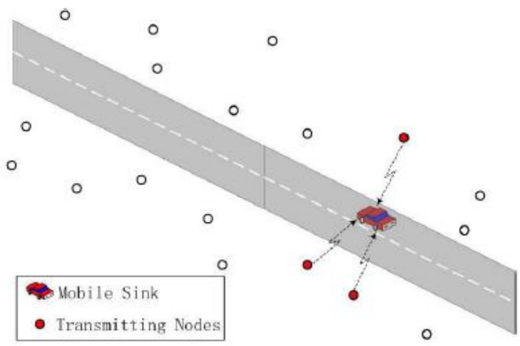

Figure 5: Wireless Sensors Network with Mobile Sinks

In designing the single node to sink transmission scheduling algorithm, consider that the sink has an estimation of its current mobility, which can be obtained from the Global Positioning System (GPS). The sink operates on a rechargeable battery and has much higher computation and communication capabilities. Individual sensor nodes are immobile, and store a number of packets for transmitting to the sink. We also assume that the sink knows the position of sensor nodes and the number of packets on every node. This can be achieved by a sensor node registration procedure.

In the design of the TSA-MSSN, a coefficient λ has been employed to control the tradeoff between the credit of successful transmission retrieval and the cost of energy consumption. The results can possibly lead to a MSSN network deployment for highway traffic surveillance applications as shown in figure 5. It is also worthwhile to note that the architecture of MSSN conforms the Embedded Wireless Interconnect (EWI) platform. EWI was suggested in [23] as the potential universal architecture for wireless sensor networks. Under EWI, the TSA-MSSN works in the Wireless Link layer (to-sink unicast module), which interacts with the upper layer by the syntax of the final state configuration.

III. Conclusions

In this paper different system architecture for wireless sensors networks have been discussed. Each model focuses on efficient deployment of sensors for target tracking, and traffic surveillance. EWI was suggested in as the potential universal architecture for wireless sensor networks. Under EWI, the TSA-MSSN works in the Wireless Link layer (to-sink unicast module), which interacts with the upper layer by the syntax of the final state configuration. The effect of buffer sizes with a high number of MSs for latency of packets has been considered where the deployed nodes suffer from frequent disconnections. Cross layer optimizations for low power wireless networks have been an active research area in recent years. Currently, cross layer optimizations need to be done in a holistic way before a new architecture is universally accepted. EWI is a promising emerging reference model after OSI.

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